# Calculation of BLM Integrator Performance

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## I. Introduction

The BLM Integrator Digitizer has been tested on BLM's in the Booster and in the Main Injector. The noise floor was measured for the BLM signal when no losses were present. This noise floor will determine the resolution of the beam loss measurement. The upper loss limit is for now assumed to be that which saturates the integrator in its default configuration. That is with an integration capacitor of 100 pF and an output limit of –10 Volts.

## II. Conversion Between Counts and Charge.

The signal out of the inverting integrator amplifier is buffered by a simple inverting op-amp before applying the voltage to the input of the ADC. The ADC has a resolution of 16 bits and an input voltage span of 5 Volts. The conversion between ADC counts and Volts at its input is

$$\frac{65{,}535\ Counts}{5\ Volts}$$

The conversion between charge into the integrator over its integration interval and Volts out is

$$\frac{Volts}{(100e-12)\ Coulombs}$$

Let the gain of the buffer amp is represented by **G Volts / Volt.** Then the conversion between Counts and Coulombs is

$$\frac{Volts}{(100e-12)\ Coulombs} * \frac{G\ Volts}{Volt} * \frac{65{,}535\ Counts}{5\ Volts} = G * \frac{Counts}{7.63e-15\ Coulombs}$$

In order to use the full output range of the integrator in its default configuration the gain of the buffer amp will be G = 0.5, and the conversion between Counts and Charge will be **15.26 femto-Coulombs per Count**.

The full scale range of the integrator with G = 0.5 will be 1000 pC.

## II. Range and Resolution for Different Time Intervals

The range and resolution in Coulombs computed thus far is for a single integration interval, 20 us. There are two other intervals of interest; 1 second and 1 millisecond. For a charge resolution determined by the measured value of Counts (RMS) of error per integration interval, the resolution for a 1 second interval will be

$$\sqrt{1/20e-6} * \frac{7.63e-15\ Coulombs(RMS) over\, 1s}{G * Counts(RMS) over\ 20ms} = \frac{1.71e-12}{G} \cdot \frac{Coulombs(RMS) over\, 1s}{Counts(RMS) over\ 20ms}$$

Likewise for a 1 millisecond interval it will be

$$\sqrt{1.0e-3/20e-6} * \frac{7.63e-15\ Coulombs(RMS) over\, 1ms}{G * Counts(RMS) over\ 20ms} = \frac{53.95e-15}{G} \cdot \frac{Coulombs(RMS) over\, 1ms}{Counts(RMS) over\ 20ms}$$

## III. BLM Application Resolution and Range Requirements

Here the requirements for the TeV and the Main Injector BLMs are explored. For the Tevatron there are both a slow loss limit and a fast or sudden loss limit. The resolution requirement has been specified to be 0.01 times the limit (1%) and the full scale range requirement is specified to be 10 times the limit.

### III.1 Tevatron Fast Loss Limit Requirements

The fast loss limit for energy deposition in the TeV magnets is given as 50 Rads. The Rads seen by the BLM is between 1/50$^{th}$ to 1/500$^{th}$ of this. The largest expected level into the BLM is 50/50 = 1.0 Rads. Ten times this, 10 Rads, is the specified full scale range required for this instance. The full scale voltage into the ADC for a 20 us integration interval will be

$$50 Rads * \frac{1}{50} * 10 * \frac{70{,}000\ pC}{Rad} * \frac{1}{100\, pF} * G = 7{,}000 * G \quad Volts$$

This voltage is too high and it is obvious that we need to consider the loss being spread over many integration periods. For G = 0.5 we can assume the loss is spread over 700 periods or 14 ms. The result would then fit in the 5 Volt input range of the ADC.

The resolution requirement will be

$$50\ Rads * \frac{1}{500} * 0.01 * \frac{70{,}000\ pC}{Rad} = 70\ pC$$

We will probably want to measure this over 700 integration periods. The resolution for a 14 ms interval and G = 0.5 is going to be

$$\sqrt{14e-3 \big/ 20e-6} * \frac{7.63e-15\, Coulombs(RMS)over\,14ms}{0.5 * Counts(RMS)over\,20ms} = 0.403\ pC \cdot \frac{Coulombs(RMS)over\,14ms}{Counts(RMS)over\,20ms}$$

## III.2 Tevatron Slow Loss Limit Requirements

The slow loss limit for energy deposition in TeV magnets is given as 800 Rads/second. The Rads seen by the BLM is between 1/50$^{th}$ to 1/500$^{th}$ of this. The largest expected level into the BLM is 800/50 = 16 Rads/second. Ten times this, 160 Rads/second, is the specified full scale range required for this instance. The full scale voltage into the ADC for a 20 us integration interval using G = 0.5 will be

$$800 Rads * \frac{1}{50} * 10 * \frac{70{,}000\ pC}{Rad} * \frac{20\ ms}{100\, pF} * 0.5 = 1.12 \quad Volts$$

The resolution requirement will be

$$\frac{800\ Rads}{Second} * \frac{1}{500} * 0.01 * \frac{70{,}000\ pC}{Rad} = 1{,}120\ pC\ over\ 1\,second$$

The conversion from the resolution in Counts (RMS) over 20 us is

$$\sqrt{1 \big/ 20e-6} * \frac{7.63e-15\, Coulombs(RMS)over\,1s}{0.5 * Counts(RMS)over\,20ms} = 3.42e-12 \cdot \frac{Coulombs(RMS)over\,1s}{Counts(RMS)over\,20ms}$$

## III.3 TeV Studies Requirements

The physicists and engineers in the Tevatron would like to have a resolution of 0.02 Rad/second as seen by the BLM in a 1 ms interval

$$\frac{0.02\ Rads}{Second} * 0.001\, Seconds * \frac{70{,}000\ pC}{Rad} = 1.4\ pC\ over\ 1\,ms$$

With the ADC buffer gain set at G = 0.5, the conversion from Counts (RMS) over 20 us to Coulombs over 1 ms is

$$\sqrt{1.0e-3 \big/ 20e-6} * \frac{7.63e-15\, Coulombs(RMS)over\,1ms}{0.5 * Counts(RMS)over\,20ms} = 0.108e-12 \cdot \frac{Coulombs(RMS)over\,1ms}{Counts(RMS)over\,20ms}$$

To achieve this specification we would need to keep the Counts (RMS) noise below 13. Note: To achieve a noise level of 0.1 Rad/second the Counts requirement is < 65.

## III.4 Main Injector Requirements (As of 6/30/04)

The requirements given for the Main Injector is to resolve 0.001 Rad over 0.001 second as seen by the BLM. This is 70 pC into the integrator over 0.001 seconds.

The conversion from Counts (RMS) to Coulombs over 0.001 seconds is again.

$$\sqrt{1.0e-3 \big/ 20e-6} * \frac{7.63e-15\ Coulombs(RMS) over\ 1ms}{G * Counts(RMS) over\ 20ms} = \frac{53.95e-15}{G} \cdot \frac{Coulombs(RMS) over\ 1ms}{Counts(RMS) over\ 20ms}$$

With a gain G = 0.5, 70 pC would correspond with 648 Counts. With G = 0.5 the full scale measurement of 1 ms will be

$$5\,Volts * \frac{1}{G} * 100\,pF * \frac{0.001\,s}{20ms} = 50{,}000\,pC$$

This corresponds to 714 Rads/second seen by the BLM or 714*50 = 36,000 Rads/second of loss.

## *IV. Summary Using a Buffer Gain of 0.5 and Count RMS of 40*

The table below compares the specifications to the case where the ADC buffer gain is 0.5 and the noise level is 40 Counts RMS. The calculations back to Rads of beam loss are not explicitly shown. For the case of the range the factor of 50 is used to go between Rads seen by the BLM and Rads of beam lost. For the resolution the factor of 500 was used.

Values given in Rads of beam loss.

| ***Application*** | ***Range*** | ***Avail. Range*** | ***Resolution*** | ***Avail. Resolution*** |
|---|---|---|---|---|
| TeV Fast Loss Limit (over 14 ms) | 50 Rads | 50 Rads | 500 mRads | 0.23 mRads |
| TeV Slow Loss Limit (over 1 second) | 800 Rads | 36,000 Rads | 8000 mRads | 977 mRads |
| Tev Studies (over 1 ms) | 0.8 Rads | 36 Rads | 8.0 mRads | 30.86 mRad |
| Main Injector (over 1 ms) | Not Specified | 36 Rads | 500 mRads | 30.86 mRad |
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